Violin-Related HCI: A Taxonomy Elicited by the Musical Interface Technology Design Space

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Abstract. Acoustic instruments such as the violin excel at translating a performer's gestures into sound in ways that can evoke a wide range of affective qualities. They require finesse when interacting with them, producing sound and music in an extremely responsive manner. This richness of interaction is simultaneously what makes acoustic instruments so challenging to play, what makes them interesting to play for long periods of time, and what makes overcoming that difficulty so worthwhile to both performers and listeners. Such an ability to capture human complexity, intelligence, and emotion through live performance interfaces is the core of what we are interested in salvaging from acoustic instruments, and bringing into the development of advanced HCI methods through the Musical Interface Technology Design Space, MITDS [12, 13].

1 MITDS – The Musical Interface Technology Design Space

Viewed as a whole, the MITDS is a framework that consists of a combination of three major areas: Music performance, Human-Computer Interaction, and the incorporation of modern technologies such as multimodal sensor interfaces and Digital Signal Processing. The MITDS is a conceptual framework for describing, analyzing, designing and extending the interfaces, mappings, synthesis algorithms and performance techniques for advanced musical instruments. It provides designers with a theoretical base to draw upon when creating new interactive performance systems. In this paper, we look primarily at just one component of the MITDS: a taxonomy of design patterns for musical interaction based on existing research and instruments.

1.1 A Taxonomy of Modern Musical Interface Design Patterns

Societies throughout history and around the world have developed formal or informal systems for classifying musical instruments, a broad field known as organology [9]. We look here at only a very small subset of the puzzle, in an attempt to clarify our understanding of how musical interfaces have developed since the separation of the controller from the source of sound became possible through various HCI methods.

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Although any attempt to classify new digital musical instruments will inevitably include nebulous zones, where a controller crosses boundaries between the categories, many studies have nonetheless proposed a set of three different types of controllers. Wanderley [20] distinguishes between 1) *Instrument-like* controllers, 2) *Augmented* controllers, and 3) *Alternate* controllers. *Instrument-like* controllers do not have any acoustic capabilities, but their interfaces resemble existing acoustic instruments. *Augmented* controllers add new gestural sensing capabilities to existing acoustic instruments, and *Alternate* controllers use electronic sensors directly, not related to any existing acoustic instrument.

1) Instrument-like controllers (interfaces resembling existing instruments)
    a. Instrument-simulating controllers (mirroring playing techniques)
    b. Instrument-inspired controllers (abstractly derived techniques)
2) Augmented controllers (traditional instruments augmented with sensors)
    a. Augmented by capturing traditional techniques
    b. Augmented through extended techniques
3) Alternate controllers (interfaces not resembling existing instruments)
    a. Touch controllers (require physical contact with control surface)
    b. Non-contact controllers (free gestures – limited sensing range)
    c. Wearable controllers (performer always in sensing environment)
    d. Borrowed controllers (VR interfaces, gamepads, etc.)

As shown above, these categories can be broken down into sub-categories in the MITDS. Distinctions are made between instrument-like controllers that attempt to *simulate* existing instruments as much as possible, and those that use existing instruments only as *inspiration* (and can be closer to alternative controllers in some cases). Within the augmented controllers category (traditional instruments enhanced with sensors), sub-categories include those that use sensors to primarily digitize a player's *existing* technique on the traditional instrument, and those that require the learning and practice of new, *extended* playing techniques through the use of sensors in non-traditional roles for that instrument. For alternate controllers, the MITDS uses categories similar to those proposed by [15], which relate to the sensing functionality of an interface relative to the human being. *Touch* controllers do not react until physically manipulated, and therefore provide haptic feedback to the performer. *Non-contact* controllers do not require contact with a physical control surface, but may have a limited range of free-air gestures (the performer can move into and out of the sensing area). *Wearable* controllers are interfaces that capture body movement, turning a performer's limb motions into potential sonic events. Finally, *borrowed* controllers are those not originally designed to be musical interfaces, such as virtual-reality motion capture systems, game controllers, etc.

2 Violin-Related HCI – Elicitation of the Taxonomy

This section investigates recent design approaches in violin-related HCI, as related to the MITDS categories above. It specifically elicits the following sections of the taxonomy: instrument-inspired controllers (category 1b above), augmented controllers capturing traditional techniques (2a), and augmented controllers capturing extended techniques (2b). Category 3 is not relevant in the context of violin-related HCI, and category 1a is not covered in detail here, as the author has been personally frustrated with instrument-simulating controllers such as MIDI violins, due to their lack of musical expressivity. The final section of this article examines the development of the Overtone Violin, which communicates with the computer via USB directly, using a protocol with much higher bandwidth and better dynamic range and expressivity than allowed by the MIDI specification. The Overtone Violin and Overtone Fiddle cross between the boundaries of this taxonomy, as they are augmented instruments that are designed to capture both traditional and extended techniques. It is nonetheless hoped that the exploration of this taxonomy will help elucidate the various design elements and tradeoffs when choosing feature sets and capabilities of an instrument's interface.

2.1 Violin-Related Instrument-Inspired Controllers

Many sensor-based interfaces have been inspired by the violin. This could be due to the fact that the violin is one of the traditional instruments that many people consider to be very expressive, giving rising to their inspiration to model newly designed instruments after it. While the physical form of the violin is not often kept, at least some portion of the player's gestures and technique are preserved.

Dan Trueman's Ph.D. dissertation titled 'Reinventing the Violin' [19] resulted in the "Bowed Sensor Speaker Array" or BoSSA, a violin-inspired controller that has many playing techniques borrowed from his background as a violinist (figure 1). A set of pressure sensors mounted between flexible material (sponges) replaces the strings, and performances usually involve a sensor-equipped violin bow, the "R-bow", which has a two-axis accelerometer and two pressure sensors between the hair and wood on the bow. This is used to play the sensor-sponges while manipulating a sensor-fingerboard called the "Fangerbored." The Fangerbored has four pressure sensors for the left hand fingers. Overall, BoSSA and the R-bow together offer performers an impressive fourteen real-time sensor data-streams, though due to practical considerations and human limitations, the number of playable dimensions is effectively reduced to nine.

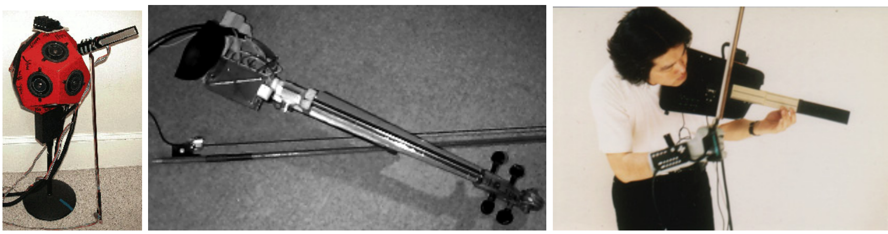

Fig. 1. Violin-inspired controllers: Dan Trueman's Bowed-Sensor-Speaker-Array (BoSSA), NealFarwell's "funny-fiddle", and Suguru Goto's SuperPolm

Neal Farwell's "funny-fiddle" project was inspired by the violin as well, and used four sensors as inputs – a sonar distance sensor between the violin and the frog on the bow, a home made linear position sensor along the neck of the violin, a tape-head from a reel-to-reel tape recorder, and a strip of magnetic tape in place of the bow-hair.

Suguru Goto's Superpolm [5] substitutes electronic sensors for strings and parameter-driven synthesis algorithms for acoustics (figure 1). The instrument is equipped with four touch-strip sensors on the fingerboard and a bow that works as a resistor ladder pressed against a voltage sensor on the bridge, plus a chin squeeze sensor for an added dimension of control. While it is impossible to use strictly traditional playing techniques on the Superpolm (since it doesn't have strings), the gestures it requires are closely related to those of a traditional violin.

2.2 Violin-Related Augmented Controllers Capturing *Traditional* Techniques

We use the term *traditional* here to refer to any instrument having strings that can be played with conventional techniques. Tod Machover's Hyperinstruments research group at the MIT Media Lab began work on this area in the early 1990s. The overall goal of the Hyperinstruments project is to provide virtuoso performers with a means of amplifying their gestures, affording supplementary sound or musical control possibilities [11]. The project resulted in several tailor-made instruments for famous musicians such as the Hypercello for Yo-Yo Ma, the Hyperviolin for Ani Kavafian, and the Hyperbow and next generation Hyperviolin for Joshua Bell. All of the Hyperinstrument's sensor systems focused on capturing *traditional* techniques.

Fig. 2. The original Hyperviolin from the MIT Media Lab, and Yo-Yo Ma performing Tod Machover's *Begin Again Again…* on the Hypercello

Stanford's CCRMA has been instrumental in developing some of the early augmented violin-family interfaces, including Max Mathews' series of electronic violins (figure 3) and Chris Chafe's Celleto (figure 4). Mathews made a number of electronic violins, all of which were closely related to normal electric violins, in that they did not have resonating bodies. Using custom electronic pickups, the sound from their strings was used as the input to electronic circuits that resonated and filtered the sound in various ways. Some of these circuits were based on the resonances of acoustic violins which were analyzed in an effort to "replace" the missing body of the instrument with electronics, while other circuits tuned the resonances to completely change the timbre of the original source of vibration, making the strings sound more like a brass instrument or a human voice [16].

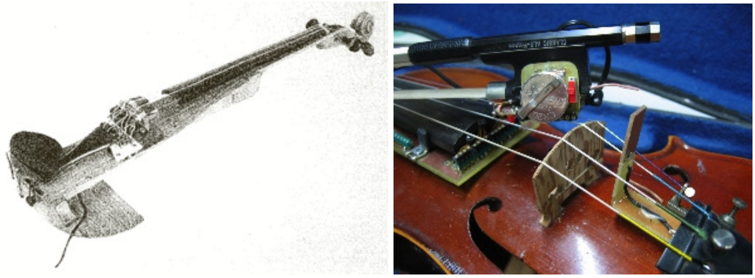

Fig. 3. left, one of Max Mathews' early electronic violins, and right, the IRCAM Augmented violin project by Emmanuel Flety, et al.

Emmanuel Flety, et al. have been developing the "Augmented Violin" (figure 3) project since 2003 at the 'Institut de Recherche et Coordination Acoustique/Musique' in Paris. Their system uses capacitive sensing to determine bow position, and is focused only on capturing gestures that are part of a *traditional* violinist's technique. Other parts of the same IRCAM project focused on software that utilizes multimodal sensor input [18], combining accelerometer and data from a video camera focused on the player in order to analyze traditional bow-strokes, and categorize them into the different techniques (martele, spicatto, detache, etc). The augmented violin project also includes the development of a reflective optical pickup system for acoustic violins, which is designed to provide discrete string signals for polyphonic pitch detection algorithms [10]. Although the pickup system they developed proved effective for its intended use (conversion of pitch to MIDI data), the decision to use a reflective rather than an occlusion based optical design resulted in a poor quality of amplified sound. Reflective designs are subject to interference from other light sources, and require a modulated infrared light signal in order to avoid disturbances from ambient light in a performance space. The bow also generates audible noise when it is above the reflective sensors.

2.3 Violin-Related Augmented Controllers Capturing *Extended* Techniques

Composer, researcher, and performer Chris Chafe developed his Celleto (figure 4), an augmented electronic cello, in collaboration with Max Mathews. The Celleto is used for both performance and research into interactive composition, where the performer controls the computer's musical flow from the sensors on the instrument. The Celleto bow uses a strain gauge sensor mounted at the mid-point, and an accelerometer placed at the frog end of the bow. Additionally, in some configurations a modified Buchla Lightning interface is used for determining the location of the bow in 2D space, allowing traditional gestures alongside extended gestures such as shaking the bow in mid-air to send accelerometer and position data.

Curtis Bahn has also developed a highly *extended* instrument, and a set of new techniques to go along with it, called the Sensor Bass, or SBass (figure 4). The SBass is used with a laptop computer and other external gear, such as the spherical speaker array developed by Dan Trueman and Perry Cook. Many sensors are attached to the electric stand-up bass, such as the pressure strips Bahn is seen playing in figure 4 [2].

Fig. 4. left to right, Chris Chafe playing his Celleto, Curtis Bahn playing his SBass, and Chad Peiper playing the eViolin made by Camille Goudeseune

The eViolin project was started by Camille Goudeseune in 1998 with the idea of "taking advantage of existing performance skill to play sound synthesis algorithms" [6,7,8]. Rather than designing new input methods, the eViolin focuses on mapping systems and software synthesis methods. The sensor technology used is an Ascension SpacePad, a device commonly used in Virtual Reality systems that measures the position of several wired sensors relative to an antenna transmitting a DC magnetic field (seen behind the player in figure 4). This system is used to capture the position and orientation of both the violin and the bow.

In the late 1980s, Australian Jon Rose collaborated with STEIM researchers on the construction of a sensor-bow, a project in which the SensorLab was used (as shown in figure 5) to capture data from a pressure sensor under the index finger and a sonar sensor to detect bow position. Rose's goal was to "bring together the physicality and dynamics of improvised music with the quick change and virtual possibilities of computer music" [17]. More recently, Rose has been utilizing the K-Bow system from Keith McMillen Instruments.

Fig. 5. left to right, Jon Rose with his MIDI Bow, CNMAT's augmented cello for Francis-Marie Uitti and a close-up of its wheel encoder (driven by the bow)

The CNMAT augmented cello [4] (see figure 5) was developed by Adrian Freed, David Wessel, and other researchers at UC Berkeley in collaboration with Francis-Marie Uitti, cellist. The sensors added to the instrument include several pressure sensors, one of which extends along the side of the neck of the instrument, a button matrix underneath the bridge, and a wheel rotary encoder below the strings that can be driven by the bow. The wheel is analogous to the "short string" extended bowing technique (bowing the strings below the bridge), as it is located below the instrument's body. All of these sensors are driven by Uitti as the performer, captured and digitized by the CNMAT connectivity processor [1]. The sensor data is used to control a software environment in Max/MSP/Jitter that the researchers have developed for her real-time performances.

3 Design of the Overtone Violin and the Overtone Fiddle through the Musical Interface Technology Design Space

While the author's Overtone Violin may not look very much like a traditional instrument, it is considered an augmented instrument within our taxonomy. This is because all of the standard violin playing techniques can be used due to the use of normal strings. Such augmented instruments can potentially include the best of both worlds through sensor-based augmentation that preserves customary performance techniques while adding powerful new possibilities for musical expression.

Fig. 6. The Overtone Violin

The Overtone Violin (figure 6) is an entirely custom built, radically augmented musical instrument that preserves the traditions of violin technique while adding a completely new set of gestural possibilities for the musician. The rationale behind the development of the instrument was to keep the expressive elements of the expert violinist, while incorporating the added benefits of gestural controllers via embedded sensors. As we have discussed, any instrument can be augmented to different degrees through the addition of extra sensors; such hybrid instruments offer musicians the familiarity and expressivity of their chosen instrument along with the extended control afforded by the sensors.

There are two ways, however, in which the Overtone Violin differs from most hybrid instruments. First, the extra sensors are used to capture a completely separate (yet complementary) set of gestures, rather than just acquiring traditional skills of the performer. Second, it is designed and built from scratch to be an entirely new, specialized instrument that continues the evolution of the violin, rather than retrofitting an existing instrument. One of the primary motivations behind the Overtone Violin is to put real-time signal processing under direct expressive control of the performer, thereby pushing the envelope of violin performance and composition into completely new areas.

There are many possibilities for using signal processing to mirror/modify the string sounds from the Overtone Violin. The instrument has independent audio outputs from each string, which help in this process by providing clean signals for pitch detection/feature tracking, and allowing different effects algorithms and spatialization techniques to be applied to each string. Signal processing is a very powerful way to enhance the violin using the traditional violin gestural vocabulary, as it preserves the nuances and subtleties of a skilled performer. But traditional instrumental techniques are not well suited for certain parametric controls needed for signal processing algorithms, so gestural controllers are needed as well. The Overtone Violin is a powerful research tool to investigate innovative approaches to combining signal processing of traditional violin sounds with gestural control of synthesis, using combinations of audio effects, synthesis techniques, and algorithms that blur these boundaries. As we have seen, there are many people who have worked on augmenting the violin in different ways, but most have focused exclusively on only a subset of these capabilities.

The Overtone Violin is an ongoing research project that has continued evolving in all three areas of musical performance, HCI, and hardware / software technologies. While this discussion focused on the technical details and development of the Overtone Violin itself and its associated software, the author has been focusing recent efforts towards the development of a new instrument called the "Overtone Fiddle"; a description of the first prototype of this instrument can be found in [14]. The Overtone Fiddle takes many of the lessons learned from the research behind the Overtone Violin, and incorporates it into a new hybrid acoustic/electric instrument in which the design has evolved to include sonic actuators inside the acoustic body of the instrument. Many new performance practices with these instruments have been explored by the author in his musical composition and performance. It is definitely long-term research, as one must allow years to fully develop new playing techniques. It is hoped that this work represents a significant step towards formulating an integrated approach to new violin development and performance; given the versatility and expressive performance possibilities of these instruments, it is impossible to foresee the far-reaching effects they may or may not have on future violin performance and composition. Audio/video clips of the Overtone Violin and the Overtone Fiddle can be found on the author's website.

4 Conclusion

The advancements in violin-related human-computer interaction described herein have taken place through the use of the author's Musical Interface Technology Design Space, MITDS. While the particular design of the author's instruments and their interfaces, interaction mappings, custom technologies, and musical performance practices emerges uniquely from personal desires and musical motivations, the overall approach is influenced by, and plays a part in the discourse of current and recent developments by others in the field. The MITDS is used to inform design decisions, resulting in the contribution of example instruments – the Overtone Violin and the Overtone Fiddle – developed through this methodology. This article has examined the use of the MITDS as a set of design patterns that are understood through the examination of existing methods of violin-related HCI. The taxonomy of research trends in the area influences the development of new systems that combine emerging technologies with musical performance and practical considerations. Ultimately, it is hoped that these considerations will be useful to others interested in pursuing similar approaches to the development of future instruments, be they violin-related or not.

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